Available online at www.sciencedirect.com
SCIENCE DIRECT
Renewable and Sustainable Energy Reviews
8 (2004) 183–192
RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS
www.elsevier.com/locate/rser

# Biofuel use and its emission of noxious gases in rural China

Wang Xiaohua *, Feng Zhenmin

*College of Engineering, Nanjing Agricultural University, Nanjing 210031, People's Republic of China*

Received 11 August 2003; accepted 30 September 2003

**Abstract**

This article discusses biomass resources and its consumption in China's farming area. In 2000, the annual yield of crop-straw was about 6900 Mt, of which 54% could be used as a source of energy. The reasonable supply of firewood was about 150 Mt. The total consumption of biofuel in China's rural area was 219 Mtce, among which crop-straw and firewood accounted for 44 and 56%, respectively. The proportion of the available heat from commercial energy over the total available heat consumed in the countryside was 0.513, and biofuel consumption decreases 3.8% annually. China is at a transition point from a period of non-commercial energy to a period of commercial energy being the main source of energy. This article discusses the effect of the discharge of noxious gases caused by the consumption of biofuel.



*Keywords:* Biofuel; Biomass resource; Noxious gases; Rural development; Rural environment; China

**Contents**



* Corresponding author. Tel.: +86-25-860-6671; fax: +86-25-860-6671.
*E-mail address:* wangxh@jlonline.com (W. Xiaohua).

1364-0321/$ - see front matter 
doi:10.1016/j.rser.2003.09.002

## 1. Introduction

During the course of global economic sustainable development, human beings are confronted with immense pressures in population, resources and the environment. The exploitation and utilization of energy is concerned with several factors: Developing countries are faced with the challenge of economic development, especially in the rural area. The energy problem in the rural area is common in most developing countries. The core of the problem is how to coordinate development energy, society, economy and the environment. Biofuel has been a source of energy which human beings have used since ancient times. It has played an important role during the historical development of human society, and has accounted for more than 15% of China's energy consumption in recent years. From the environmental point of view, it is part of the essence that composes the ecosystem and will not cause greenhouse warming [1,2].

As a very important part of the national energy system, energy supply and consumption in the rural area has a great influence on the development of the rural society, economy and ecological environment. China is a large developing agricultural country, with its rural area largely populated. These areas used to be scarcely supplied with commodities and the consumption of commercial energy per capita was low. Noncommercial energy was the main source of energy consumption, which was mainly local biofuel. The increase in population and the sterility of soil gave prominence to the contradiction between the demand and supply of energy, which led to the over-consumption of the local biomass resources and the direct threat to the environment [3–5].

With the rapid development of the rural economy and the improvement of peasants' living conditions, the energy consumption structure of the rural area is undergoing great changes. The demand for commercial energy is rapidly increasing, especially in some rural areas with good economy and commodities which consume the main part of the available energy. This led to the superabundance of the original biomass energy source. The improper disposition of the superabundant biomass polluted the atmosphere, waters, and the ecological environment [6–8].

Confronted with the pressures from both economical development in the rural area and environmental protection, China must realize that the sustained increase in the national economy changes the traditional production mode of energy and the way consumption exploits and utilizes biomass energy resources. This article discusses: (1) the present situation and development of the biomass resources and its consumption in the rural areas of China, (2) the outflow discharge of poisonous gases due to the consumption of biofuel, and (3) the changes of the total outflow discharge in the rural area after the substitution of fuels.

## 2. The supply of biomass energy resources in the rural area

China is abundant in biomass resources, which mainly includes straw and stalk and firewood. According to the statistics in 2000, the annual yield of crop straw was about 0.69 billion metric ton, which could be converted into 338 Mtce. Recently, the straw and stalk resources have increased at a rate of 1.4% annually. Among all the straw and stalk, the losses during recycling in field and collection account for 16.2%, forage 28%, papermaking raw materials 2.1% and energy resources 53.6%.

According to the survey on forest resources, forests covered 1.34 million km$^2$ in China which reasonably supplies more than 150 Mt firewood annually, or 86 Mtce. The coverage rate of forest rose from 8% in the early 1950's to the present 14%. But the average forest area per capita is only one sixth of the global level. At present, the total supply can meet the total demand, but with unbalanced development in different areas.

## 3. The energy consumption in the rural area

Energy consumption in the rural area mainly includes the consumption during the production and that of daily use. The former mainly involves the energy consumed in farm production and the production of rural enterprises, while the latter involves the energy consumed in cooking, baking, breeding, boiling water and the use of domestic electric appliances.

The total energy consumption in the rural area in 2000 was 670 Mtce (see Table 1), which accounted for 44% of the 1522 Mtce of the total national energy consumption (including non-commercial energy) [9]. Among the total, 456 Mtce was commercial energy, accounting for 35.0% of the national primary commercial energy consumption (1303 Mtce). Among the total consumption, coal accounts for 43.7%, electric power 14.8% (1 kWh = 0.404 kgce), fuel oil 7.9%, straw and stalk 18.4%, and firewood 14.3%. The annual growth rate of the three commercial energy consumption was 7.8%, 8.6% and 6.5%, respectively. Although the commercial energy consumption in the rural area has been growing at a rate of 7.9%, the consumption per capita was only 45% of the national average value, and 21% of the average value for the city, which showed an obvious gap. The commercial

Table 1
The total energy consumption in rural area of China in 2000 (Mtce) [13]

| | Commercial energy | | | | Non-commercial energy | | | Total |
|---|---|---|---|---|---|---|---|---|
| | Coal | Fuel oils[a] | Electricity | Total | Straw | Firewood | Total | |
| For production | 175.27 | 45.55 | 64.69 | 285.51 | – | 14.96 | 14.96 | 300.47 |
| For livelihood | 118.01 | 7.57 | 34.44 | 160.02 | 123.60 | 80.52 | 204.12 | 370.00 |
| Total | 293.28 | 53.12 | 99.13 | 455.53 | 123.60 | 95.48 | 219.08 | 670.47 |

[a] Include LPG.

energy was mainly used by enterprises, agricultural production and transportation, which accounted for 65%, while that used in daily life accounted for 35%. The 219 Mtce noncommercial energy consumed in the rural area was used mainly as domestic fuel, in which straw and stalk and firewood accounted for 43.6% and 56.4%, respectively.

### 3.1. The present consumption situation of biomass energy

The total consumption of biofuel in the rural area in 2000 was 219 Mtce, among which straw and stalk accounted for 124 Mtce, firewood accounted for 95 Mtce, and only 15 Mtce of which was used by rural enterprises, the rest of which was mainly used in livelihood. Fig. 1 shows that the biomass energy accounted for 55% of the total energy consumed in livelihood.

If we do not take the electric power consumed in cooking into consideration, the thermal efficiency of the coal-burning furnace was 28%, and that of the straw and firewood-burning furnace was 18%. Thus the total available heat for cooking was 75.6 Mtce, or 81.3 kgce (i.e. 1559.2 kcal/d) per capita. The total available heat provided by coal and charcoal and straw and stalk and firewood, and oil was 45.2%, 29.1%, 19.6% and 6.1%, respectively (see Fig. 2).

The proportion of the available heat from commercial energy over the total available heat consumed (PAHFCE) reflects a very important index, namely, the quality of the domestic energy consumption (DEC). The PAHFCE in the rural area for 2000 was 0.513, which indicates that along with the rapid growth of the family income, China is at the turning point of the transition from the period of non-commercial energy to the period of commercial energy being the main source of energy.

The biomass energy's taking the place of commercial energy has led to much overplus of the straw and stalk which supply and demand used to be in a balance. Having not found an economical and effective method to use the straw and stalk, peasants just burnt it, which causes a waste of resources and pollution.

China's countryside has been dependant on local biomass energy source, which was prone to be insufficient for demand. But, relying on local resources (especially on biomass) too much may come to the end so that the resource consumption goes beyond the reasonable amount of supply. The excessive exploitation of biomass

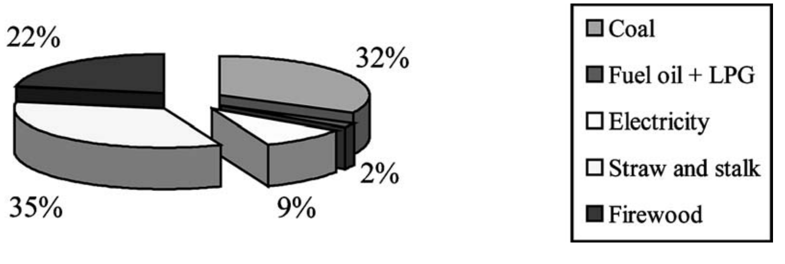



Fig. 1. Rural household energy consumption in 2000.

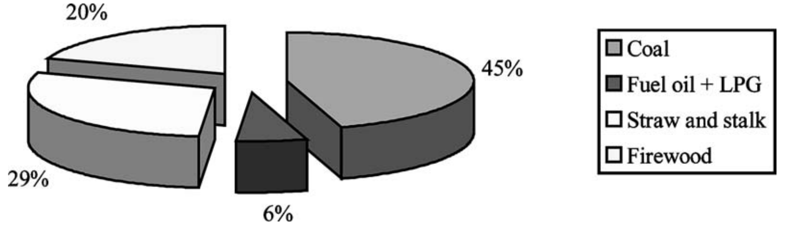



Fig. 2. The total available heat structure for cooking.

energy source has resulted in further soil erosion and decrease of organic substance content. The main causes for China's rural energy shortage are listed as follows. Firstly, no sufficient natural energy resources were available. Not enough straw and stalks were obtained due to the lower agricultural production level. Forest mountains were not protected properly, leading to less fuel wood available. Secondly, high population pressure on limited resources exited. Rural population growth was obviously higher than that of cities. Thirdly, no commercial energy supply was for rural areas under previous in-plan economic system. Lastly, inefficient self-built stoves with heating efficiency lower than 10% were widely used, resulting in unreasonably higher energy consumption per capita. Families had to send their surplus labor to collect every kind of biomass fuels, at the cost of rural ecology destruction. Rural household energy shortage caused a much higher social cost than personal cost.

In most areas, the 1980s marked a major shift away from subsistence farming towards a more commercialized and industrialized rural economy. Township and village industry gradually dominated rural output. More families with higher income appeared. Increased supply of straw and stalks due to the rapid development of agricultural production resulting from a household responsibility system, made it possible to basically solve the fuel shortage problem. Fig. 3 shows the change of biomass energy consumption between 1989 and 1998, and it reached the climax at the end of 1980s. There was a movement of rural laborers out of agriculture to town and village enterprises (TVEs) or to towns and cities. The trend toward urbanization first decreased and then increased the demand for energy, and

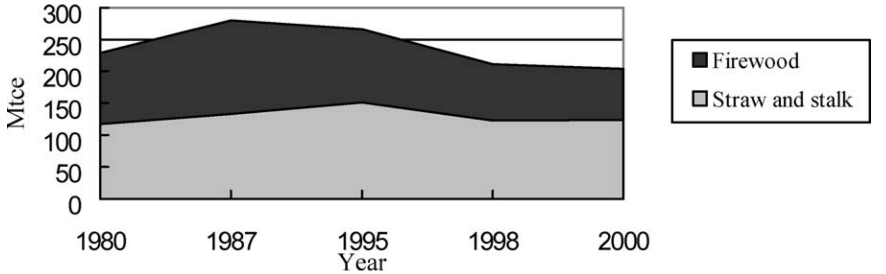



Fig. 3. The change of biomass energy consumption in 1989–2000.

also speeded up the need for cleaner and more efficient sources, indicating a start of rural energy commercialization. With rural living standards increased and the improvement of commercial energy availability, the biomass energy is taking the place of commercial energy, and consequently, the total consumption of straw and stalk and firewood decreased rapidly.

### *3.2. The change of the biomass energy consumption along with time*

From 1991 to 2000, the annual growth rate of total energy consumption in the rural area was 3.6%, while biomass energy consumption decreased at a rate of 3.8%. The proportion of consumed biomass energy over the total consumed energy in livelihood decreased from 84 to 55%. The proportion of the consumption of straw and stalk as biofuel over their output decreased from 79 to 37%. The annual consumption of straw and stalk has decreased at a rate of 3.2% in recent years. The decrease of using straw and stalk was about 7 Mt. There was an estimated 1400 Mt of straw and stalk that was replaced, or was thrown away or burnt (see Table 2). Owing to the closing of hillsides to livestock grazing and fuel gathering to facilitate forestation, plus the replacement by coal and charcoal, the consumption of firewood dropped from 140 Mtce in 1985 to below 81 Mtce in 2000.

### *3.3. The differences of biofuel consumption among different districts*

Because of the big differences in natural resources and economies, the energy supply in the rural areas is more dependent on local natural resources that led to a big difference in the utilization of biofuel among different places. Table 3 depicts the utilizations of straw and stalk in six main districts and the annual growth rate of related indexes in recent years. As for the usage of straw and stalk as fuel per capita, and the proportion of straw and stalk consumption over daily energy consumption in rural areas, the southern areas are higher than the northern areas while the northeast, north and east are higher than the northwest, southwest and west areas. The proportion of straw and stalk consumption per capita over total energy consumption in the north is higher than that in the south. In the northern areas, especially north China and northwest areas, the change rate of using straw and stalk as life energy is slower than that in the southern areas. The rate of replacement by commercial energy in the southern areas is obviously faster than that in the northern areas. As for the firewood resources, the coverage of forest in the east is larger than the west, and the south is larger than the north.

## 4. The emission of poisonous gases caused by the domestic biofuel consumption

According to the consumption of biofuel in China's rural areas in 2000, Table 4 gives the result after using the conversion standard presented by Streets [10], i.e. the emission factor of $SO_2$ by the burning of straw and stalk and firewood is

Table 2
The change of the biomass energy consumption along with time [13,14]

| Year | Rural energy consumption (1000 tce) | Energy consumption for livelihood (1000 tce) | | | Percent of energy consumption for livelihood (%) | | Percent[a] (%) | Per capita straw consumption (t) |
|---|---|---|---|---|---|---|---|---|
| | | Total | Straw | Firewood | Straw | Firewood | | |
| 1991 | 568218.5 | 360034.0 | 162126.8 | 103029.8 | 45.0 | 28.6 | 74 | 0.46 |
| 1992 | 569793.8 | 320474.2 | 135498.0 | 93472.9 | 42.3 | 29.2 | 58 | 0.32 |
| 1993 | 584999.8 | 350112.9 | 153536.6 | 89430.3 | 43.9 | 25.5 | 59 | 0.34 |
| 1994 | 610247.5 | 365258.2 | 152157.4 | 94573.6 | 41.7 | 25.9 | 60 | 0.34 |
| 1995 | 665049.6 | 381724.9 | 150923.8 | 100134.4 | 49.5 | 26.2 | 56 | 0.31 |
| 1996 | 639623.1 | 340694.9 | 119967.7 | 82989.1 | 35.2 | 24.4 | 48 | 0.31 |
| 1997 | 655851.3 | 352736.4 | 121385.3 | 83495.0 | 34.4 | 23.7 | 39 | 0.30 |
| 1998 | 672130.0 | 364560.0 | 122800.0 | 84010.0 | 33.6 | 23.0 | 38 | 0.29 |
| 1999 | 630320.0 | 353460.0 | 125020.0 | 77910.0 | 35.4 | 22.0 | 37 | 0.30 |
| 2000 | 670470.0 | 370000.0 | 123600.0 | 80520.0 | 33.4 | 21.8 | 36 | 0.29 |

[a] The proportion of the consumption of straw and stalk as biofuel over their output.

Table 3
The utilizations of straw and stalk in the six main districts[a]

| Areas | Rural energy consumption (10 000 tce) | Energy consumption for livelihood | | | Percent[b] (%) | Straw and stalk consumption (t/capita) |
|---|---|---|---|---|---|---|
| | | Total (10 000 tce) | Straw and stalk | | | |
| | | | (10 000 tce) | (%) | | |
| Northeast China | 1937.12 (−3.8) | 1081.86 (−5.7) | 550.64 (−6.4) | 50 (−4.6) | 47 (−12.3) | 1.04 (−0.7) |
| North China | 2553.09 (4.2) | 1310.56 (2.5) | 523.67 (2.2) | 41 (−0.2) | 57 (−0.1) | 0.97 (1.6) |
| East China | 2906.81 (5.9) | 1305.36 (−0.4) | 650.27 (−7.7) | 40 (−11.1) | 58 (−9.2) | 0.79 (−2.7) |
| Southwest China | 2435.28 (−2.6) | 1612.42 (−7.7) | 317.13 (−14.2) | 1 (−16.8) | 30 (−13.8) | 0.62 (−3.6) |
| Northwest China | 431.50 (−10.5) | 302.48 (−8.7) | 100.20 (−8.3) | 25 (−0.4) | 28 (−6.8) | 0.70 (2.8) |
| South China | 2043.25 (−1.7) | 1029.52 (−3.6) | 264.79 (−6.3) | 27 (−11.4) | 58 (−2.9) | 0.53 (−1.9) |

[a] The numbers in brackets are the annual growth rate (%) of related indexes in 1991–1996.
[b] The proportion of the consumption of straw and stalk as biofuel over their output.

37.5 t/PJ, that of NOx is 91 t/PJ and 45 t/PJ, respectively, and that of $CO_2$ is 1.247 t/t and 1.436 t/t, respectively. So, $CO_2$ was 585.5 Mt, $SO_2$ was $22.9 \times 10^4$t and NOx was $44.3 \times 10^4$t. $SO_2$ accounted for 1.1% of the total outflow discharge (19.95 Mt) in China, NOx 5.0%. If we take the energy consumption of coal and LGP into consideration [11,12], the emission of $CO_2$ was 902 Mt.

Along with the replacement by commercial energy in the rural area, the consumption of straw and stalk and firewood is dropping gradually. But because part of the straw and stalk is burnt in the field, which is incomplete combustion, the emission of poisonous gases by each unit of straw and stalk is increasing. Therefore, the drop-off rate of the poisonous gas emission is between 1 and 2%, though the consumption of biofuel decreases at an annual rate of 3.1%.

If we consider the substitution function of domestic energy, i.e. the drop-off rate of the consumption of biofuel will necessarily lead to an increase commercial energy, we can deduce the outflow discharge of the poisonous gases by meeting the demand for total available heat. Suppose the consumption of biofuel still decreases

Table 4
The emission of poisonous gases caused by the domestic biofuel consumption

| | Energy consumption (Mtce/PJ) | Carbon dioxide (Mt) | Sulfur dioxide ($10^4$ t) | Nitrogen oxides ($10^4$ t) |
|---|---|---|---|---|
| Straw | 123.60/3622 | 346.41 | 13.59 | 33.00 |
| Firewood | 80.52/2360 | 226.68 | 8.85 | 10.62 |
| Total | | 573.09 | 22.44 | 43.67 |

at 3% in the coming years, the demand for total available energy remains constant, half of the available heat of the replaced straw and firewood is provided by LPG, half by coal and charcoal, then the consumption of coal will increase at 1.5% annually, LPG at 8–10%, which will eventually lead to an increase in the total emission by burning biofuel after substitution, especially the emission of $SO_2$.

## 5. Conclusion

China has abundant biomass energy resources. In 2000, the annual output of straw and stalk was about 0.69 billion tons, or 338.24 Mtce coal equivalent, which is increasing at 1.4% annually. The annual output of firewood is about over 150 Mt, or 86 Mtce coal equivalent. The consumption of various energies in the rural area is 670 Mtce, which accounts for 44.0% of the total national consumption. The biofuel mainly used in rural livelihood is 219 Mtce, of which straw and firewood account for 56.2 and 43.8%, respectively. The biomass energy accounts for 55.1% of the total consumption of energy in livelihood. The acquired available heat in cooking is 73.8 Mtce, 80.6 kgce (1545.8 kcal/d) per capita. Of the total available heat that is provided by the coal, straw, firewood and oil accounts for 43.7%, 18.4%, 14.3% and 7.9%, respectively. The proportion of the available heat from commercial energy over the total available heat consumed in China's rural areas is 0.513, which indicates that along with the rapid growth of the family income, China is at the turning point in the transition from a period of non-commercial energy to a period of commercial energy being the main source of energy. During the period of 1991–2000, the annual consumption of biofuel decreased by 3.8%, the proportion of biomass over consumed energy in livelihood dropped from 84.2 to 55.1%. There is a 7 Mt annual decrease of straw, and 1400 Mt straw and stalk is thrown away or burnt annually. There is a great difference in the utilization of biofuel in different areas. The emission of poisonous gases caused by the consumption of biomass energy is: $CO_2$ was 573.1 Mt, $SO_2$ $22.4 \times 10^4$ t, NOx $43.6 \times 10^4$ t. The total emission by burning biofuel after substitution, especially the emission of $SO_2$, will increase.

The biomass energy's being substituted by commercial energy has led to much overplus of the straw and stalk. Having not found an economical and effective method to use the straw and stalk, peasants just burnt it, which caused the waste of resources and environmental pollution. The government should make the corrective policies about the effective utilization of straw and stalk, encouraging the development and application of technologies of recycling straw in the field and of gasification of straw and stalk, appealing for the research application on the utilization of straw and stalk.

## References

[1] Dincer I. Renewable energy and sustainable development: a crucial review. Renewable & Sustainable Energy Reviews 2000;4:157–75.

[2] Rural Energy Committee of Energy Research Society of China. Chronicle of events of China's rural energy. Beijing: China City Press; 1994.
[3] Energy Sector Management Assistance Program (ESMAP), 1996. Energy for Rural Development in China: An Assessment Based on a Joint Chinese/ESMAP Study in Six Counties. Rep. No.183/96. World Bank, Washington, DC.
[4] Work Bank/Energy Sector Management Assistance Program (ESMAP), 1989. County-level Rural Energy Assessments: A Joint Study of ESMAP and Chinese Experts. Rep. No.101/89. World Bank, Washington, DC.
[5] Peter C. China's rural energy system and management. Applied Energy 1999;64:229–40.
[6] Wang XH. Situations and trends of China's rural household energy consumption. Journal of Nanjing Agricultural University 1994;17(3):134–41.
[7] Wang XH, Feng ZM. Survey of rural household energy consumption in China. Energy—The International Journal 1996;21(7/8):703–5.
[8] Wang XH, Feng ZM. A survey of rural energy consumption in the developed regions of China. Energy—The International Journal 1997;22(5):511–4.
[9] National Statistical Bureau, P.R.China. Statistical yearbook of China. Beijing: China Statistical Press; 2001.
[10] Streets DG, Waldhoff ST. Biofuel use in Asia and acidifying emissions. Energy 1998;23:1029–42.
[11] Lenzen M. Primary energy and greenhouse gases embodied in Australian final consumption: an input–output analysis. Energy Policy 1998;26:495–511.
[12] Wang GH. Analysis method on reducing emission of $SO_2$ and $CO_2$ by rural energy construction. Transations of the Chiese Society of Agricultural Engineering 1999;15(1):169–72.
[13] Editorial Board of China's Rural Energy Yearbook. Rural energy yearbook (2000) of China. Beijing: China Agricultural Press; 2001.
[14] Editorial Board of China's Rural Energy Yearbook. Rural energy yearbook (1997) of China. Beijing: China Agricultural Press; 1998.